DETERMINATION OF SOIL EROSION PARAMETERS FOR MALAYSIAN CONDITIONS USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM APPROACH

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ABSTRACT

The use of Universal Soil Loss Equation (USLE) for predicting an average annual soil loss in any area is influenced by the characteristics of the environmental setting of that specific area. In the previous studies that have been carried out in Malaysia, the parameters used were based on various studies in many other areas, and this affected the accuracy of the result. This study is carried out in Pasoh Forest Reserve which covers an area of 8,100 km^2 located in Pahang, Negeri Sembilan and Selangor. The elevation of the study area range from 40 meters to 1760 meters. Permanent crop constitutes the largest land cover of the study area (46 %), followed by forest (45%), cropland (5 %), and settlement and non-agriculture lands (4 %). The accuracy of the results was tested using regression analysis and Root Mean Square Error (RMSE). Notably, the results of this study shows strong correlation between factors that were generate and the RMSE values are smaller. It is noted that crop management (C,) slope length and steepness (LS) and soil erodibility (K) factors that have been applied for USLE model in this study gave better results compared to other previous studies using inapplicable environmental characteristics. Estimation of soil loss in the year 1995 showed an average of 7.97 t/h/yr and the average soil loss for the year 2003 was 6.83 t/h/yr, a decline of 15 percent. Secondary forest, oil palm, sundry non tree cultivation and rubber have contributed to the highest amount of soil loss for both years. Error estimation for the year 1995 shows that annual rate of soil loss is 18.93± 2.37 t/yr compared to 16.59 ± 1.13 t/yr for the year 2003, apart from experiencing loss of soil surface ranging from 4 mm to 8 mm in a period of 8 years. Thus, the approach used in this study is not only suitable for Malaysia, but can also be applied to any other country with similar environmental characteristics.

ABSTRAK

Penggunaan *Universal Soil Loss Equation* (USLE) bagi menganggar purata kehilangan tanah tahunan, dipengaruhi oleh ciri-ciri persekitaran sesuatu kawasan. Dalam kajian yang dijalankan di Malaysia sebelum ini, parameter yang digunakan adalah berdasarkan kajian-kajian yang dijalankan di dalam mahupun luar negara; sekaligus mempengaruhi ketepatan hasil yang diperolehi. Kawasan kajian yang terlibat adalah di sekitar Hutan Simpan Pasoh seluas 8,100 km^2 yang terletak antara Pahang, Negeri Sembilan dan Selangor. Topografi berbukit bukau dan ketinggian di kawasan kajian adalah antara 40 meter hingga 1760 meter. Tumbuhan kekal merupakan litupan tanah terbesar (46%), diikuti oleh hutan (45 %), tanaman tidak kekal (5 %), pembangunan dan bukan aktiviti pertanian (4 %). Analisis regrasi dan *Root Mean Square Error* (RMSE) dilakukan untuk menguji ketepatan keputusan yang diperolehi. Hasil menunjukan faktor yang dijana melalui kajian ini memberikan perhubungan yang lebih kuat serta nilai RMSE yang lebih rendah. Penjanaan faktor pengurusan tanaman (C), kecuraman dan panjang cerun (LS) dan erodibiliti tanah (K) pada model USLE dalam kajian ini memberikan hasil lebih tepat berbanding kajian sebelumnya yang mengunakan ciri persekitaran yang kurang sesuai dipraktikkan di Malaysia. Hasil menunjukan, kawasan kajian mengalami kehilangan tanah 7.97 t/h/yr pada tahun 1995, berbanding tahun 2003 (6.83 t/h/yr) iaitu penurunan sebanyak 15 peratus. Hutan sekunder, kelapa sawit, tanaman pokok bukan baka dan getah adalah gunatanah utama yang menyumbang kepada kehilangan tanah pada kedua-dua tahun. Anggaran ralat tahun 1995 adalah 18.93± 2.37 t/yr berbanding tahun 2003 (16.59 ± 1.13 t/yr), selain mengalami kehilangan tanah permukaan 4 milimeter (mm) hingga 8 mm dalam jangka masa 8 tahun. Oleh itu, pendekatan yang digunakan dalam kajian ini bukan sahaja sesuai untuk Malaysia, malah sesuai digunapakai di negara-negara lain yang mempunyai ciri-ciri persekitaran yang sama seperti Malaysia.

TABLE OF CONTENTS

CHAPTER I

INTRODUCTION

1.1 Background

Soil erosion is one form of soil degradation and commonly related to other problems such as low levels of soil organic matter, loss of soil structure and soil acidity. Although erosion is a natural process, it can pose many problems when occurrences are due to human activities.

Soil erosion can be defined as a process of detachment and transport of soil particles from one place to another (Singer and Munns, 1999; and Cutler, 2006). With respect to land conservation and practice, soil erosion in tropical and semi arid regions considered as a hazard traditionally associated with agriculture (Morgan, 1995). This occurs mainly due to rainfall intensity, poor soil conditions and improper landuse management.

Today soil erosion is considered as one of the most serious natural resource depletions in the world. Over the past several thousand years, deforestation, fuel wood, overgrazing, agriculture and industrialization activities have contributed to the greatest soil erosion problem (Marsh, 1984; Oldeman *et al.*, 1990; Stott and Sullivian, 2000). Figure 1.1 shows five most common causes of soil erosion regions in the world.

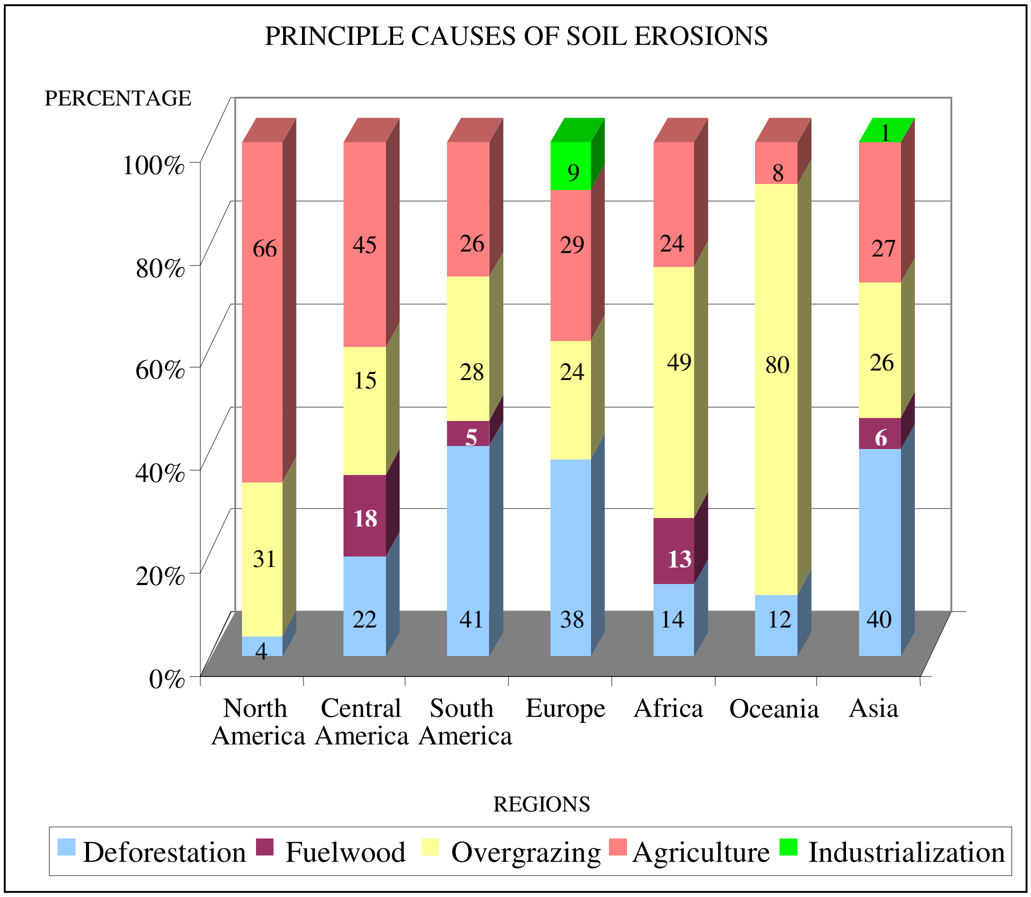

Figure 1.1: Principle causes of soil erosions in different regions in the world

Source: International Soil Reference and Information Center, 1991

The main causes of soil erosion are overgrazing (35 percent), deforestation (30 percent) and agricultural activities (28 percent). Overgrazing causes degradation when the soil loses it fertility and sparse vegetation cover. This will allows raindrops to erode the surface and thus, removal of the entire standing crop can increase erosion and slides.

According to the United Nations Food and Agriculture Organization (2008), 1.5 million people in this world may stave due to land erosion problem. Rising of land degradation cause by erosion can reduces crop yields and this will threaten food of the world population. To solve this problem, this issue leads to public attention in the form of government, Malaysian organizations and public for environmental protection. That's the reason why regulation of soil erosion along with its prevention and control is important to be taken as a key in the soil conservation issues today.

1.1.1 Factors affecting erosion

The factors affecting erosion can be divided into 2 categories; natural and human induced (Dingman, 1994; and Wu *et al.,* 2004). Precipitation and slope steepness comprise natural factors for the most part, while human factors consist of development or activities related to agriculture, mining and constructions. Such activities generally remove the protective vegetation cover, resulting in accelerated erosion by both water and wind. Natural factors commonly affect the upper soil layer as compared to human induced factors. Both contribute a significant amount of soil loss due to water and wind erosion.

1.1.2 Soil erosion agents

Water and wind are the major erosive agents that determine the erosion type. These agents are both unsteady and non-uniform in intensity (rain) and velocity (wind). Both erosion agents occur in different environment; water erosion is wet, while wind erosion is dry. Soil erosion by water is the dominant geomorphic process for much of Earth's land surface (Terrence *et al.*, 2001). Water erosion also contributes to the detachment, transport and deposition of soil particles. Figure 1.2 below shows the impact on the soil surface by water erosion.

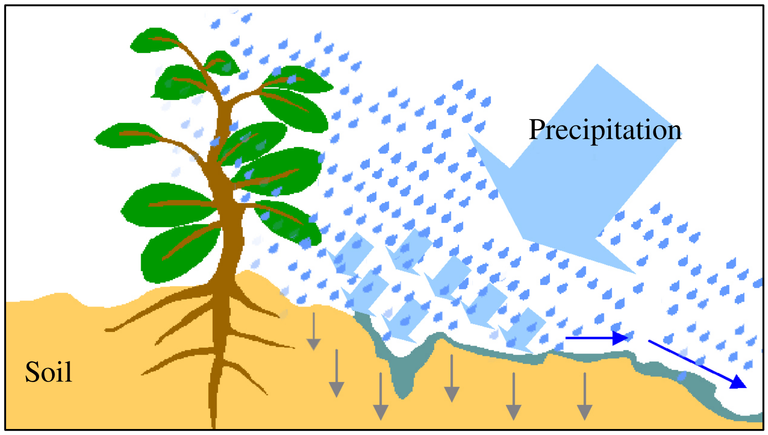

Figure 1.2: Impact on the soil surface by water erosion

Source: Terrence *et al.*, 2001

When runoff occurs, water will accumulate as it flows downstream, resulting in a larger volume of water traveling at incremental velocity. Soil erosion by water is a major worldwide problem compared to wind erosion (Singer and Munns, 1999). By selectively removing organic matter and clay, water erosion not only removes but also may reduce the soil chemical capacity to retain added nutrients.

On the other hand, wind erosion is a phenomenon largely created through detachment processes. This type of erosion occurs when the forces applied by the wind are greater than the resistance of the soil. Soil particles move by wind in one of the three ways; surface creep (rolling or sliding along surface), saltation (bouncing and dislodging other particles on impact) and suspension (continuously carried in the air). Figure 1.3 shows soil particle movement through wind erosion.

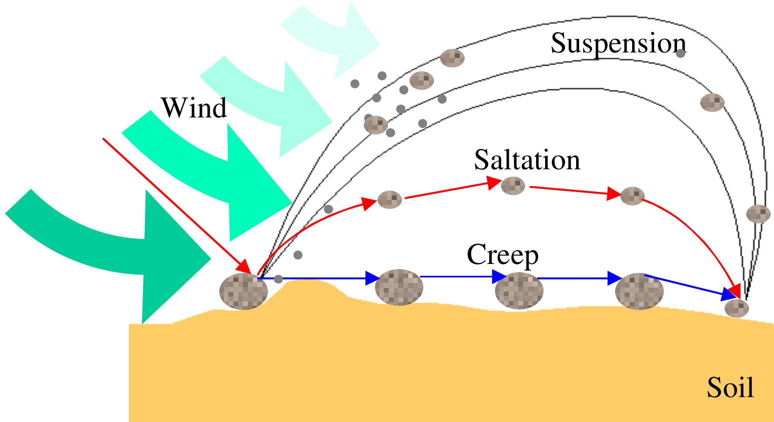

Figure 1.3: The movement of soil particles by wind erosion

Source: Terrence *et al.*, 2001

A major difference between both erosion processes is the direction of occurrence. For erosion by water, runoff and sedimentation always flow in downstream, while wind may blow in any direction during storm.

In Malaysia, erosion by water is the major concern compared to the erosion by wind. Malaysia as tropical countries receives a heavy rain annually. This reason will lead to the soil erosion, particularly for the deforested and overgrazing areas.

1.2 Problem statement

Soil erosion can affect the land and its inhabitants in both on-site and off-site effects. On-site effect is directly created through the loss of soil nutrients. This effect is particularly crucial on agricultural land because it involves the loss of soil quality, structure and soil stability. While in off-site effect, movement of sediments and agricultural pollutants into watercourses are the major problem, leading to sedimentation in rivers and disruption of ecosystems.

Today, the rate of soil erosion exceeds the rate of soil formation over wide areas resulting in the depletion of soil. Rate of soil loss can determined by in-situ measurement of annual precipitation, elevation, crop cover and practiced erosion control factors. Using USLE model, the rate of annual soil loss (A) can be predicted based on parameters such as; annual rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), crop management (C), practice and erosion control (P) factors.

Most measurements and determination of parameters used in USLE equation are taken from studies conducted outside Malaysia, in particular, Europe. Malaysia differs greatly in terms of vegetation, due to the leaf size, tree diameter and soil formation, compared to the temperate countries. Erosion particularly in forested and cultivated areas needs the accurate measurement of rate of soil loss. By using the existing parameters in USLE, the soil loss rates may contain a certain amount of error either too high or too low for Malaysia.

1.3 Significant of the study

Studies by Food and Agriculture Organization (FAO) estimated that 140 million hectares of soil particularly in Africa and Asia are subjected to degradation by year 2010, unless better methods of land management are utilized (International Union of Geological, 1994). Hence, this study is significant to be applying since deforestation and great development activities were rapidly take place now days. It is therefore imperative to analyze C, LS and K factors with respect to the Malaysian setting, since the physical conditions in Malaysia such as topography, weather, vegetation and soil types are very much different from Europe and temperate countries especially in arid and semi-arid areas.

The annual erosivity (R) and erosion control practice (P) factors will not be taken into account, as a specific algorithm already exists to determine each factor. For example, the erosivity (R) factor is calculated using the rainfall intensity for the study area. The erosion control practice (P) factor is determined from values based on the degree of slope and the ratio of soil loss. For both factors, the measurement is not affected by topographic or environmental conditions. It's used the constant value to derive the factors. That's the main reason *R* and *P* factors did not be measured and analyzed in this study.

1.4 Objectives

The main objective of this study is to establish three main factors of USLE; *C, LS* and *K* to suite the Malaysian conditions. To achieve this, the study consists of four specific objectives as outlined below:

a) To derive the most suitable crop management (C) factor of USLE for use in Malaysia condition derived from satellite remotely sensed data.
b) To determine and minimize 'systematic error' in computing slope length and steepness (LS) factor of USLE respectively in terrain and slope areas.
c) To determine soil erodibility (K factor) of the USLE particularly in sloped and forested areas.
d) Assessment of annual soil loss using all parameters of the USLE determined in objectives (a), (b) and (c).

1.5 Scopes of study

This study consists of four aspects, hence:

a) Landsat 5 TM images were used to derive Vegetation Indices such as SVI, Sqrt (IR/R), VI, TNDVI and NDVI for crop production assessment in the study area. The vegetation indices with the best correlations will be used to calculate the *C* factor on the USLE model for this study.

b) The effects of systematic errors that consist of DEM artifacts were removed to analyze the exact values of *LS* factor in the study area using GIS techniques.

c) Soil permeability, bulk density, drainage and percentage of the soil porosity were used to determine exact values for *K* factor for most of the slope and forested areas. Geological aspects were used as a comparison to extract *K* values; especially for the series of soils that have no percentage of clay, fine silt, very fine silt and organic matter.

d) Simulation of *C, LS* and *K* factor values were done to analyze the variation in the amount of annual soil loss in the study area.

1.6 Study area

This study was conducted in an old growth, lowland dipterocarp forest within the Pasoh Forest Reserve (lat 2°59′N, long 102°18′E). This study area covers three states namely Pahang, Negeri Sembilan and Selangor, with a total area of 810 000 hectares (8100 km^2). There are six forest reserves located in the study area; Kemasol Forest Reserve, Kenaboi Forest Reserve, Garau Forest Reserve, Berembun Forest

Reserve, Triang Forest Reserve and Pasoh Forest Reserve with an elevation range of 40 to 1760 meters. There are 13 rivers in study area; Sg. Pahang, Sg. Serting, Sg. Batu, Sg. Melaka, Sg. Terachi, Sg. Rembau, Sg. Triang, Sg. Jerang, Sg. Candin, Sg. Benus, Sg. Kongkol, Sg. Bentung and Sg. Semantan (Figure 1.4).

Pasoh Forest Reserve is located 8 km from Simpang Pertang, Negeri Sembilan and approximately 70 km southeast of Kuala Lumpur. Surrounded by oil palm plantations on three sides and adjoin to a virgin hill dipterocarp forest on the northeast, the reserve area encompasses 2450 hectares. Maintained by the Forest Research Institute of Malaysia (FRIM), Pasoh is declared as International Biosphere Reserve under the UNESCO Man and Biosphere Program (Forest Research Institute of Malaysia, 2003).

Thirteen years records by Pasoh Dua station, this study area receives annual rainfalls between 1469 to 2350 mm (Zulkifli, 2004). The monthly rainfall pattern shows a bi-modal distribution with peaks in March to May and September to December. The steepest part covers a stretch in the upstream of the study area. The highest erosion potentials are on steep areas especially to the west, south and east. Slope gradient along the main river in the study area shows a range of 0 to 750 meters above sea level (masl). Theoretically, elevations above 1000 meters above sea level (masl) are considered highly vulnerable to erosion while elevations below 200 masl are expected to have low erosion risk.

Pasoh Forest Reserve and the surrounding areas were selected for this study due to the rapid agriculture practices and physical developments. This development has changed the existing landuse or land cover vastly. Proper land management is necessary to control the occurrence of land degradation in study area.

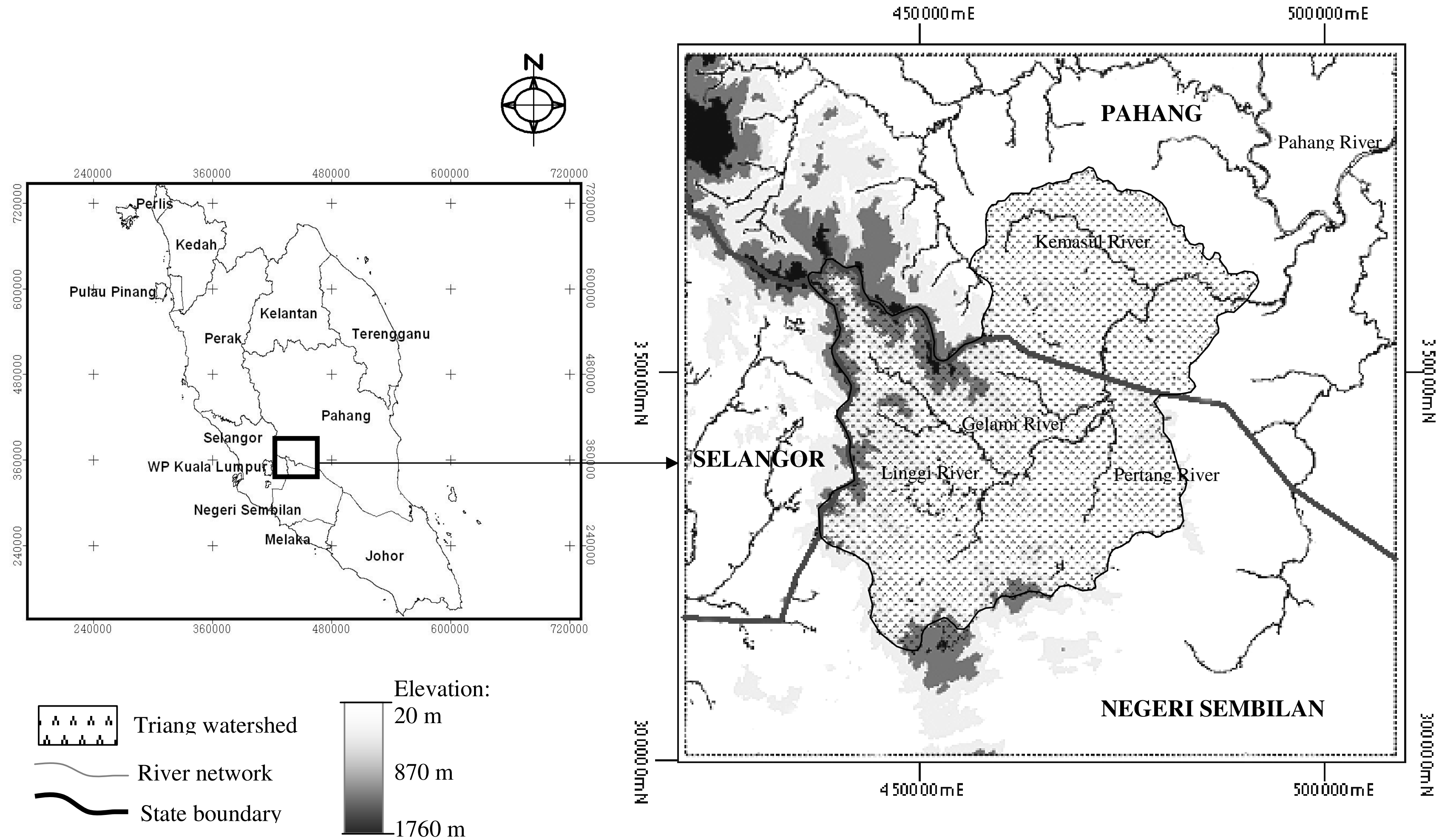

Figure 1.4: Study area

1.7 Summary

Soil erosion removes valuable topsoil, results in lower yields and higher costs of production. Hence, it is very important to study the regulation of soil erosion since forests and plantations cover more than 60 percent of Malaysia. Pasoh Forest was selected as the area under this study; (a) to determine and assess crop management (C) factor for Malaysian conditions derived from satellite remotely sensed data, (b) to determine and minimize 'systematic error' in computing slope length and steepness (LS) factor respectively in terrain and slope areas, (c) to determine soil erodibility (K factor) particularly in sloped and forested areas, and (d) assess annual soil loss using all parameters of the USLE determined in objectives (a), (b) and (c). To perform this study, USLE was selected as a model to determine rate of soil loss in the study area. Details on soil erosion model and reasons for choosing USLE to perform this study will be discussed in the next chapter.

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APPENDIX

APPENDIX A

RADIOMETRIC AND ATMOSPHERIC CORRECTION

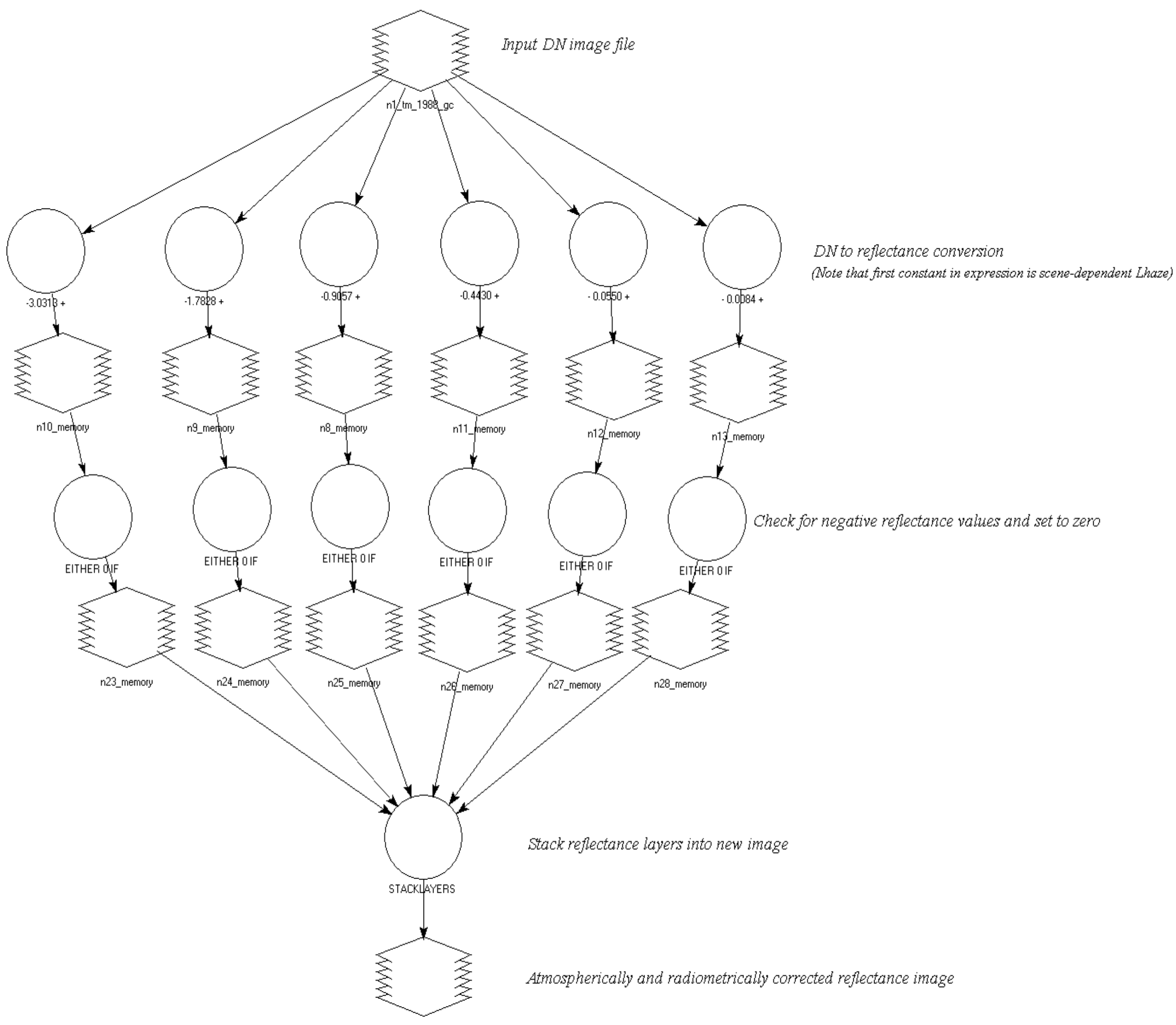

Figure shows COST model via spatial modeler in the ERDAS software